RESEARCH ANALYSIS CORPORATION

Aspects of Cost

and Utility Analysis in Planning

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FOREWORD

This paper was prepared for presentation at the Twelfth International Meeting of the Institute of Management Sciences on 8 Sep 64, in Vienna, Austria.

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INTRODUCTION

In this paper, some aspects of planning in preparation for resource-allocation decisions among alternatives, which are generally made under uncertainty, will be discussed from the pragmatic viewpoint of a practicing analyst. No new theory will be expounded. We will be concerned only with that area of economic analysis in which the inputs are not commensurable with the outputs. (The terms "input" and "output" will be used throughout this paper in their general meaning and not in the specialized meaning attached to them in input-output or intersectoral economics.)

INPUT-OUTPUT RELATIONS

First, let us review what the commensurable and incommensurable aspects of input and output are. The costs of the inputs are established and measured in the market; there is an objective price mechanism for the inputs.

Where the outputs are also determined and measured in a market as prices the economic theory of the firm applies. Planning decisions can be based on the relation of discounted marginal revenue to discounted marginal cost. Inputs and outputs are objectively determined and commensurable with each other and among alternatives. This condition is largely representative of the activities in the private sector of the economy.

Where there is no market and hence no price for the outputs, two types of incommensurability, partial and total, can be distinguished:

Partial incommensurability exists when a part of the output (tangibles) can be measured in market terms and reasonably objective approximations of comparable output prices can be made, but the remainder of the output (intangibles) cannot be measured on an objective scale quantifying worth, value, utility, or similar concepts. Substitute measures on the observable output can be made objectively but not in the same units as the inputs, i.e., costs. Attempts to impute prices to these outputs are not objective. The part of the output that can be expressed in market terms can be discounted. The part of the output that cannot be measured on a market scale cannot be discounted because the concept of "present value" has no operational meaning in this application. Domestic public works and public services are representative of such activities, producing benefits within the social system making the resource allocation. A technique for analysis of these input-output relations is called "cost-benefit analysis" as distinguished from what might be called the "cost-revenue analysis" applicable in the private sector.

Total incommensurability exists when the output of the activity cannot be measured in market terms at all; political and military externally directed

goods and services are typical of such activities. The objectives to which their outputs are directed are essentially states of minds of other social systems whose interests generally do not coincide with those of the social system that makes the resource allocation for the inputs. There are no objective scales on which to measure the accomplishment of the objectives by the outputs, and they cannot be discounted to a present value. Substitute measures of the observables can be made; they are generally not commensurable among different activities and are not commensurable with the inputs. A technique for analyzing these input-output relations is called "cost-effectiveness analysis." Uncertainty must, of course, be considered in each of the input-output relations previously discussed.

In the following discussion, we will not be concerned with cost-revenue analysis but only with cost-effectiveness analysis and with the incommensurable aspects of cost-benefit analysis. In both cases the problems of relating costs to utility—problems compounded by consideration of time and uncertainty—challenge the analyst.

QUANTIFICATION

The more theoretical treatments of such allocation problems tend to assume the problems of the quantitative description of costs, risks, and outcomes as solved, leaving the decision maker—a slightly more farsighted descendent of economic man—to accept a choice of a course of action resulting from applying explicit decision rules, e.g., maximization or minimization criteria, to the quantitative descriptions of the alternatives. From a practical standpoint, analyses for planning that are focused on this model of resource-allocation decisions are likely to require time and effort considerably in excess of resources that can reasonably be made available for the task of analysis. Their focus also causes such analyses to slight the very significant role of intuition and judgment.

The elusive and subjective character of the outputs for which there is no objective price-determining market mechanism makes efforts to develop quantitative expressions of benefit or effectiveness very complicated, except for the purely arbitrary and subjective figures of merit. To approximately quantify utility, benefits, or effectiveness, substitute measures or scales are required for which values can be determined objectively. A single measure is rarely adequate. Not all components of the output are positive. The negative elements of output are often difficult, if not altogether impossible, to quantify. (The destruction of such irreplaceable natural resources as wilderness areas having principally aesthetic value, by the building of some dams and hydroelectric power plants. is only one example of incommensurable negative utility of the output.) The relation of substitute measures to utility is not necessarily linear or homogeneous. Among different programs, these measures or scales differ and may not be independent, thus complicating the problem of quantitative marginal utility evaluation still further. None of these measures is in the same terms as the input, i.e., costs; none is discountable in an operationally meaningful manner.

To permit the application of quantitative decision rules and to cope with incommensurability, many different output scoring, voting, or weighting schemes

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have been proposed. Some of these schemes are intended to lead to ordinal preference rankings among different projects. Other schemes are designed to obtain cardinal values for the outputs to permit objectively commensurable comparison of the outputs of different activities, measurement of differences in outputs, and imputed commensurability of outputs with inputs. In addition to the multidimensional, nonlinear, and inhomogeneous aspects of utility measures, any cardinal values that could be derived are not absolute; they are relative to, and relevant only within, the set of all outputs so described in any given problem of choosing among alternatives.

Large models could perhaps handle the multiplicity of output variables and their interactions to compute unidimensional measures. The feasibility of such models appears questionable in view of the dynamic nature of such resource-allocation problems as the rate of change of the objectives and the alternatives in the present and foreseeable future. Aside from the physical creation of such models the time required to obtain the multitude of objectively derived factors and coefficients needed for the measures of outputs for each decision situation makes it likely that, by the time the measure of the output has been calculated and the conclusions tested for sensitivity to assumptions, the problem will have changed.

MODELS AND STRUCTURE

If we accept the support of the intuitive and judgmental characteristics of allocation decisions involving incommensurables as a criterion for the information required of the analyses, a very different approach follows. The purpose of the analysis is changed. It must sharpen the intuition, provide insight, and identify sensitivities, interactions, and implications; it serves to marshal, organize, and present relevant quantitative and qualitative information so that the decision context assumes a gestalt, and marginal worth, uncertainty, time, and marginal cost of the alternatives can be evaluated by informed judgment at various levels.

In implementing this approach, the emphasis is on the analysis of the structure of the alternatives. This requires descriptive, not necessarily mathematical, models of the relations between the input and the output of the alternatives. This relation cannot be established directly but is made possible by three types of interrelated submodels: an effectiveness model, a system and organization model, and a cost model. The effectiveness model relates substitute measures of effectiveness to measures of performance in the context of operational environment and use. The systems and organizational model relates the measures of performance to physical specifications, quantities, and activity rates of all required resources in an organizational context. The cost model relates the physical specifications, quantities, and activity rates to estimates of costs through factors and estimating relations.

These submodels are developed following detailed functional and information-requirements analysis of the objective. Successively more detailed flow diagrams are used to examine the functions to be performed and the information to be generated, processed, and acted on. The next step in the analysis is the identification of the dimensions of effectiveness: those for which substitute measures

can be obtained and those that must be described qualitatively. Interfaces are defined, uncertainties described, and the interactions to be modeled are selected. The one or more effectiveness submodels designed for a given problem can always illuminate only a part of the output. To model is always to abstract from reality and to identify and examine relations in the real world, but explicit discussion of what was not modeled and of the implications of the exclusion is required.

From each of the effectiveness submodels, performance measures are derived that describe the physical output of a system and of an organization that operates and supports it consistent with an operational concept. The detailed flow-diagram analyses of the effectiveness models identify physical resources and operational procedures; in the system and organization model, the flow diagrams are transformed into a functional organizational structure from which the physical specifications, activity rates, and quantities of all required resources can be tabulated.

One or more cost submodels relate the physical resources to costs through estimating relations and factors. Such costs need not be precise in an absolute sense; they are used in a relative manner and therefore completeness and consistency are of primary concern, as is reflected in the preceding steps of the analysis. The detailed discussion of cost-estimating relations and factors is beyond the scope of this paper; they are generally developed from cost data on the same or analogous resources by statistical-regression techniques. The nature of the costs to be estimated differs in an important aspect from cost-revenue analysis: previous expenditures called sunk costs are excluded from consideration. They cannot be amortized. If they have created resources that can be used for the alternatives under consideration, such inherited assets will serve to reduce future costs. It is useful to group the estimated future costs into categories that help to illuminate the allocation problem. An example is the segregation of recurring from nonrecurring costs. A further subdivision might be nonrecurring costs that are a function of qualitative but not quantitative characteristics, e.g., development costs and nonrecurring costs that are a function of qualitative and quantitative characteristics, e.g., acquisition costs. Recurring costs might be divided into materiel and personnel costs, for example. The time horizon of the estimates will vary with the decision problem at hand but will be consistent for all alternatives.

The submodels previously discussed describe a way of analyzing given sets of alternative input-output relations. It is also desirable to order these relations into categories structured by type of allocation decision and level of aggregation. One such category might consist of alternative individual projects or systems for the same objective, e.g., the alternatives for a local transportation system or for a type of military unit, say, an armored battalion. Another category might consist of individually dissimilar projects organized as a system for a common objective, e.g., alternatives for a regional development project or alternative military forces for a specific theater of operations. A third category might consist of different projects and groups of projects for different objectives, e.g., urban renewal, public education, border defense, and space exploration.

The model structure briefly discussed provides a useful mechanism and framework for these aspects of analysis of resource-allocation planning problems:

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- A structured hierarchy of objectives.

- Explicit description of alternatives for each objective.

- Recognition of interactions and interdependencies.

- Explicit discussion of uncertainty.

- Objectively determined measures on the observable component of output as substitute indicators of the accomplishment of the objectives.

- The complete resource requirements, structured in an operationally and organizationally functional manner.

- The estimated future costs of the alternatives.

- Explicit identification of nonquantifiable and nonpositive components of the outputs.

- Recognition of interdependencies among elements of the analysis.

- A basis for the comparison of the alternatives with each other and with other projects relevant to the decision context.

The format of presentation of this information is, of course, flexible but will generally contain tabular and graphic displays of the relations among time, costs, quantitative descriptions of benefits or effectiveness, and qualitative descriptions of unquantifiables and uncertainties.

DISCOUNTED AND TIME-PHASED COSTS

To discount the input costs to a present value is conceptually correct and arithmetically simple. There are, however, a number of practical problems that make it desirable to display time-phased inputs instead of or in addition to discounted costs:

- Only those elements of the alternatives that are de facto postponable investment choices can be properly discounted.

- Cost estimates of future projects are sensitive to the interest rate used to discount; this sensitivity increases, of course, with the time horizon—and, incidentally, the error spread of the cost estimates increases also.

- Discount interest rates and time horizons would need to be used consistently over all projects on which the definitive resource-allocation decision will actually be made.

- There is at present no objective mechanism for establishing an interest rate, or interest rates, for such discounting.

- The political realities of the programming, budgeting, and appropriation processes that follow the planning study make it desirable to present cost consequences by year.

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- Comparison with other cost streams and aggregation of cost
  streams at successively higher levels in the allocation-
  decision hierarchy must permit evaluation of the rate of change
  of such streams from the standpoint of fiscal policy.

In some cases, especially where constraints must be considered, it may
be desirable also to display the physical resource requirements by year.

An additional advantage of the display of time-phased input, time-phased
output, and uncertainty information is that it tends to force the explicit con-
sideration of additional imponderables and unquantifiables in the process of
evaluation, thereby further contributing to the heuristic purposes of the analysis.

MARGINAL UTILITY AND COST

The purpose of planning is to select a preferred course of action from
alternatives. At the level of an individual project or system the problem is a
choice among mutually exclusive possibilities. If one can compare the alterna-
tives at several levels of the same future costs and identify the alternative
having the highest benefits or effectiveness, or if one can compare them at
several levels of effectiveness and identify an alternative having the lowest
future cost making due allowance for inherited assets, the problem is relatively
straightforward. But if one of the choices is to continue with an existing capa-
bility as is often the case, then the equal-cost or equal-effectiveness comparison
is usually not possible. To develop, acquire, and operate a new system is likely
to yield more effectiveness or benefit, and to cost more, than to continue to
operate the system on hand. Now the choice problem becomes a different one:
is the increase in output worth the increase in input? To gain insight into this
output-worth problem and into the problem of relative output worth among dif-
ferent individual projects or systems, it is useful to compare relative prefer-
ences at a higher level of aggregation.

At higher aggregations the alternatives consist of different mixes, i.e.,
types and quantities, of individual projects or systems. This change in the
reference framework and meaning of alternatives is essential for the marginal
evaluation.

The optimal input for a given individual system or project does not nec-
essarily correspond to the input available to that system, when a group or mix
of projects and systems is evaluated. In most practical resource-allocation
problems it is not feasible to allocate the available resources to projects at
their most efficient points until the resources are exhausted and to cancel the
remaining projects. Instead, the resources available must somehow be allo-
cated among many, if not all, of the preferred individual projects. If the re-
sources are not sufficient to furnish the input to each project at its most efficient
point, a completely different choice context exists. Marginal substitutions of
inputs among individual projects must be evaluated not only against marginal
changes in the output of these projects, but the changed contribution of each
project to the output of the mix of projects to which the total available resources
are to be allocated must also be evaluated.

MARGINAL SUBSTITUTION

As we have already observed, measures on the output that permit rigorous optimizations cannot be made available. The discipline of marginal substitution under a constant cost constraint provides a workable technique for the evaluation of alternatives at each level in the hierarchy of objectives and allocation decisions. The descriptive analysis of the alternatives previously discussed is specifically designed to facilitate the subjective integration of the diverse components of output; the equal-cost constraint limits the subjective evaluation to the output.

The function of the analyst, then, is to present to the planner or decision maker at a given level in the hierarchy an unranked set of alternatives, fully described as noted above, at that cost level that will satisfy all projects under consideration at their most efficient points. Following an explanatory briefing that describes the projects and the purpose of the analysis the planner or decision maker is then given successively lower cost constraints within which to order and adjust the alternatives until a satisfactory understanding of the relative utilities has been attained. Iterations may be desirable.

It is not uncommon that the process of analysis and evaluation, of examination and reexamination of the objectives and the alternatives (particularly their structure and resource implications), and the search for dominant as well as dominated alternatives, leads to the revision of the objectives as well as to the design of new or the redesign of given alternatives. Because of the insights gained, they will become the preferred solutions. This is particularly valuable where the given alternatives are found to be very sensitive to uncertainties. A good analysis will point to additional alternatives that will be good choices under many or all of the contingencies.

It is suggested that the analysis of cost and utility described in this paper provides a preference ordering on the alternatives, an insight into their worth, and a preparation for subsequent programming and budgeting tasks, when resource-level requirements must be established and justified.